Extra-Corporeal Cardiopulmonary Resuscitation (ECPR) for Cardiac Arrest Patients-3-Year Experience in the Era of Left Ventricular Decompression

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Abstract

Background

Cardiac arrest has been a great threat, regardless of its occurrence in or out of the hospital (OHCA and IHCA). ECMO has been regarded as the last resort to save these endangering lives. This prospective cohort intended to clarify how ECMO-assisted CPR (ECPR) benefited patients of cardiac arrests, both OHCA and IHCA, and addressed the survival benefit of left ventricular decompression.

Methods

Consecutive patients of OHCA and IHCA, refractory to resuscitation and without certain exclusion criteria for mechanical support, were enrolled since 2018. Primary endpoint was in-hospital mortality.

Results

From 2018 Jan. to 2021 Mar., 147 patients of both OHCA and IHCA were put on ECPR. Acute coronary syndrome took 63.3%. Rate of weaning-off from ECMO/modified LVAD was 45.6%, and the in-hospital mortality rate was 67.3%. Peak serum lactate (10.9 ± 5.5 vs. 16.4 ± 7.7 mmol/L, $p < 0.001$) and left ventricular ejection fraction (35.8 ± 20.6% vs. 26.7 ± 21.7%, $p = 0.029$) during mechanical support were of prognostic significance. The low-flow time was not correlated with these two prognostic parameters and in-hospital mortality in our series. Forty-five patients with poorer left ventricular function were put on modified LVAD, which rendered survival benefit over VA-ECMO by 3 days: 1st day mortality (VA-ECMO vs modified LVAD 18.6% vs. 2.2%, $p = 0.008$); 3rd day (35.3% vs 17.8%, $p = 0.034$). The Kaplan-Meyer analysis depicted the survival benefit of modified LVAD (log-rank $p = 0.024$)

Conclusion

Our prospective cohort, enrolling both OHCA and IHCA patients put on ECPR, implied that fair outcomes could be achieved in both groups, as long as high quality CPR could be persistently applied, regardless of the low-flow time. Peak serum lactate and LVEF were proved again to be closely correlated to outcomes. Moreover, the procedure of LV decompression could render further survival benefit to those with poorer LV function.

Background

Cardiac arrests, both out-of-hospital (OHCA) and in-hospital (IHCA), threatened hundreds of thousands of lives each year. Extra-corporeal membranous oxygenation (ECMO), composed of a blood pump, gas exchange device, conduits with vascular access and heat exchanger, has been advocated as the last resort to rescue those patients refractory to our resuscitation efforts[1, 2]. The incorporation of ECMO in our resuscitation efforts has been referred to as extra-corporeal cardiopulmonary resuscitation (ECPR). Despite the ushering of the concept of ECPR, the American Heart Association (AHA) still reported insufficient evidence to recommend the routine use of ECPR for patients with cardiac arrests in 2019. It only suggested the application of ECPR when conventional CPR failed[3]. In addition, left ventricular (LV) decompression, either by active apical venting or passive upstream left atrial drainage, has been introduced to avoid overload of the failing left ventricle[4]. The combination of ECMO and LV decompression in cardiac arrest has not been explored extensively.

We conducted this prospective cohort since 2018, during which our protocol of LV decompression was well established. The study aims to clarify the efficacy of ECPR with or without LV decompression in rescuing patients of cardiac arrest.

Methods

Setting

This study was conducted in a tertiary referring medical center in Northern Taiwan, where at least 450 open-heart surgeries were performed each year. Patients of OHCA were put on CPR by either bystander or emergent medical technician (EMT), and followed by efforts made by the medical team in emergency service in our hospital. Resuscitation of IHCA were provided by dedicated medical personnel, including senior nurse practitioner, medical resident, senior nurse, respiratory therapist, and duty attending physician. All members providing CPR are certified by authorized board of advanced cardiac life-support (ACLS) in Taiwan. The ECMO task force consisted of a duty cardiovascular surgeon, a surgical resident, a perfusionist, a nurse practitioner, and staff of Operation Theater if needed. A designated perfusionist was assigned to record all relevant data. All patients put on ECMO were all taken care in the cardiovascular intensive care unit (CVICU), in which around 6,900 patient-days was accommodated annually. The cause of cardiac arrest was delineated by a committee organized by the intensivist of CVICU. All patients without meaningful responses after the resuscitation would be put on target temperature management (TTM) for 24 hours, unless there was contra-indications, such as uncontrolled bleeding diathesis (gastro-intestinal or intracranial hemorrhage), and refractory hypothermia related cardiac arrhythmias. We adhered to contemporary clinical guidelines to apply adjunctive medical treatment for specific disease entity, such as myocardial infarction, cardiogenic shock, heart failure, pulmonary embolism, etc[5–7].

Patients and procedures

Cardiac arrest of any cause, which mandated CPR for more than 10 minutes, would activate the ECMO task force by the CPR team. The task force was responsible for the decision to proceed or not, after assessment and discussion with the CPR team and the afflicted family. We excluded patients, who were elder than 80-years-old, presented with active massive bleeding, bed-ridden status, severe irreversible brain damage, with known terminal disease with less than 6 months of life expectancy, and those who already requested “Do Not Resuscitate” (DNR). The study protocol was approved by the institutional review board. Informed consent for any necessary invasive procedure and data collection were obtained either from the patient's legitimate family. The whole study has been approved and scrutinized by the Institutional Review Board of Far-Eastern Memorial Hospital, New Taipei City, Taiwan.

Procedure

In general, the interval between activation and arrival of ECMO task force in our hospital was around 10 min 24/7, as there was always a duty cardiovascular surgeon. In addition, we have always made one set of heparinized saline (2 U/ml)-primed circuit and centrifugal pump available. Indwelling an antegrade reperfusion catheter in the superficial femoral artery has been our routine to avoid any distal limb ischemia. The ECMO circuit was connected to a temperature console, immediately after the system was established. As the setup of ECMO system was accomplished, a brain computed tomography would be performed, in order to exclude any intra-cranial pathology. Echocardiographic surveillance was performed on daily basis, in order to clarify myocardial status, focusing on left ventricular ejection fraction (LVEF), right ventricular function and other relevant complications. Only the LVEF taken in 72 hours of resuscitation was enlisted, in order to avoid the influence of myocardial stunning.

Under one of the following conditions, we would apply procedures of LV decompression, such as direct surgical LV apical venting, upstream LV drainage via one of the upper pulmonary veins either by surgical sternotomy or percutaneous trans-septal approach. The indications included: 1. Refractory lung edema, 2. Echocardiographic evidence of marked LV distension, 3. Refractory ventricular tachycardia/fibrillation, 4. Elevated LV end-diastolic pressure (LVEDP), either illustrated by pulmonary arterial occlusive pressure (PAOP) by Swan-Ganz catheter (PAOP > 25 mmHg), or by direct measurement during LV catheterization (LVEDP > 25 mmHg) in the cath lab[8]. The drainage tube of LV decompression was bridged to the ECMO venous tube, connected to the inlet of the centrifugal pump together. The arterial access returning to the patient would be left as the original ECMO arterial access, or implanted to the ascending aorta directing antegradely, if the patient underwent any surgical intervention, such as coronary artery bypass graft surgery (CABG), or the aforementioned surgical LV decompression. If the systolic function of right ventricle (RV) recovered (defined by echocardiographic evidence: direct 2D visual or tricuspid annular plane systolic excursion (TAPSE))[9], the femoral venous access of ECMO would be de-cannulated, and the drainage tube of LV decompression would be connected to the inlet of centrifugal pump directly. As the patient’s oxygenation became fair, we would taper the support of our ECMO’s membranous oxygenator, which would be removed after the patient became independent of it. In order to unify the terminology, the whole system, consist of a tube draining the LV, the centrifugal pump, and the arterial access returning to the patient, would be referred to as “modified left ventricular assist device (modified LVAD)”. In the context, the terms of “LV decompression” and “modified LVAD” were synonymous and interchangeable.

Success of weaning-off of ECMO or modified LVAD is defined as no deterioration of hemodynamics, necessitating repeated application of any mechanical support or mortality in 72 hours after discontinuation. Bridge to implantable ventricular assist device, such as Heartware™, or heart transplant was also regarded as a successful weaning-off.

The primary endpoint was in-hospital all-cause mortality. Successful weaning-off of ECMO/modified LVAD is regarded as 2nd endpoint.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation or median, depending on the normality test results. Categorical variables are expressed as number and percentage of patients, and were compared by using $\chi2$ and Fischer's exact tests. Group means for continuous variables were compared by Student's t-test or the Wilconxin test as appropriate. The low-flow-time was defined as the beginning of witnessed CPR to the establishment of ECMO flow. The mortalities were evaluated at the intervals of 1, 3, 7, 14, 21, 28-days and as a whole by overall in-hospital mortality, which was also compared b y$\chi2$ and Fischer's exact tests. Kaplan-Meyer survival curve was adopted to illustrate the difference between ECMO with/without LV decompression. The correlations were analysed by a correlation coefficient, $\chi2$ test for categorical variables and Pearson's correlation for continuous variables. All statistical tests were two tailed, and a p value < 0.05 was deemed statistically significant. The analysis was done with Statistical Package for Social Sciences software (SPSS ver.12.0 for Windows).

Results

From 2018 Jan. to 2021 Mar., there were 147 consecutive patients of cardiac arrests put on ECPR. The enrollment of the study was withheld in Apr. 2021, because the COVID-19 pandemic in northern Taiwan interrupted the normal conduct of resuscitation and activation of ECMO task force, especially for those patients presenting with OHCA, who might pose unknown infectious threat to our medical staff. Our enrollee were 58.8 ± 12.3 years-old, and a majority of them was male (86.4%). IHCA patients comprised 57.8% of our study group. Acute coronary syndrome accounted for 63.3% of the underlying cause of cardiac arrest. It took less than 30mins for the ECMO task force to establish the system after activation, both for OHCA and IHCA patients (25 ± 12 vs. 27 ± 14 min, $p = 0.355$). The overall success of weaning of ECMO/modified LVAD was 45.6%, and the primary endpoint of in-hospital all-cause mortality was achieved by 67.3% of the enrollee, in other words, 32.7% of our patients of cardiac arrests survived to discharge. Our patients were put on mechanical support for 8.7 ± 15.5 days, and they would stay in the hospital for 22.0 ± 24.0 days. (Table 1)

Table 1
Demographics of all patients, categorized by OHCA and IHCA

	OHCA	IHCA	Overall	p value
Case No.	62	85	147	
Age (yr)	57.3 ± 11.2	60.1 ± 13.0	58.8	0.085
Sex				
Male	57(91.9%)	70(82.4%)	127(86.4%)	0.143
Female	5(8.1%)	15(17.6%)	20(15.6%	
Hypertension	29(46.8%)	51(60.0%)	80(54.4%)	0.132
Diabetes	17(27.4%)	32(37.6%)	49(33.3%)	0.218
Smoking	30(48.4%)	37(43.5%)	67(45.6%)	0.616
Low flow time# (min)	80.7 ± 44.5	45.6 ± 31.3		< 0.001
ECMO esta. Time* (min)	25 ± 12	27 ± 14		0.355
Peak lactate (mmol/L)	14.8 ± 6.5	14.2 ± 8.1		0.657
LVEF+ (%)	26.1 ± 21.1	33.5 ± 21.7		0.079
Diagnosis				0.317
CAD/MI@	43(69.4%)	50(58.8%)	93(63.3%)	
pulmonary embolism	2(3.2%)	3(3.5%)	5(3.4%)	
myocarditis	1(1.6%)	2(2.4%)	3(2.0%)	
peri-open heart shock&	0(0%)	4(4.7%)	4(2.7%)	
other shock	15(24.2%)	20(23.5%)	35(23.8%)	
Aortic dissection	1(1.6%)	6(7.1%)	7(4.8%)	
ECMO status				

Time interval between witnessed CPR and the establishment of ECMO flow

* ECMO establish time: interval between the activation of ECMO task force and the establishment of ECMO flow

+ Left ventricular ejection fraction

@ Coronary artery disease/myocardial infarction

& Shock during open heart surgery

	OHCA	IHCA	Overall	p value
VA ECMO	43(69.4%)	59(69.4%)	102(69.4%)	1.0
Modified LVAD	19(30.6%)	26(30.6%)	45(30.6%)	1.0
Wean off	27(43.5%)	40(47.1%	67(45.6%)	0.738
ECMO/VAD days	7.1 ± 10.0	9.9 ± 18.5	8.7 ± 15.5	0.280
Hospital stay (day)	17.9 ± 21.9	24.9 ± 25.1	22.0 ± 24.0	0.080
Mortality	42(67.7%)	57(67.1%)	99(67.3%)	1.0
# Time interval between witnessed CPR and the establishment of ECMO flow				
* ECMO establish time: interval between the activation of ECMO task force and the establishment of ECMO flow				
+ Left ventricular ejection fraction				
@ Coronary artery disease/myocardial infarction				
& Shock during open heart surgery				

Regarding the primary endpoint of in-hospital all-cause mortality, both survivors and those who succumbed to were similar in demographics, including age, co-morbidities (diabetes, hypertension, dyslipidemia and current smoking). There was no difference in the rapidity of setting up the ECMO system (survivor vs. mortality: 23.8 ± 11.2 vs. 27.3 ± 14.0 mins, p = 0.129). The proportion of OHCA in both groups was not different, either (41.7% vs. 42.4%, p = 0.93). Male predominance was more significant in the mortality group (75.0% vs. 91.9%, p = 0.005). Duration of ECMO or modified LVAD did not vary significantly (survivor vs. mortality: 12.2 ± 20.9 vs. 7.1 ± 11.9 days, p = 0.065). Wean-off rate was much higher in the survivor group (93.8% vs 22.2%, p < 0.001). Longer hospital stay (40.0 ± 25.6 vs. 13.2 ± 17.5 days, p < 0.001, 95% conf int 19.6, 33.9) was also expected among survivors. Peak serum lactate level (survivor vs. mortality 10.9 ± 5.5 vs. 16.4 ± 7.7 mmol/L, p < 0.001, 95% conf int. -8.1, -3.1) and LVEF during mechanical support (35.8 ± 20.6 vs. 26.7 ± 21.7%, p = 0.029, 95% conf int.1.0, 17.4) were significantly correlated with prognosis. (Table 2)

Table 2
Demographics categorized by survival and mortality

	Survival	Mortality	p value
Case No.	48	99	
Age (yr)	58.5 ± 10.2	59.2 ± 13.2	0.768
Sex			0.005
Male	36(75.0%)	91(91.9%)	
Female	12(25.0%)	8(8.1%)	
Hypertension	21(43.8%)	59(59.6%)	0.07
Diabetes	16(33.3%)	33(33.3%)	1.0
Smoking	27(56.3%)	40(40.4%)	0.07
OHCA	20(41.7%)	42(42.4%)	0.93
IHCA	28(58.3%)	57(57.6%)	0.93
Low flow time# (min)	60.0 ± 44.1	60.4 ± 39.8	0.98
ECMO/VAD days	12.2 ± 20.9	7.1 ± 11.9	0.065
Hospital stay (day)	40 ± 25.6	13.2 ± 17.5	< 0.001
ECMO esta. Time* (min)	23.8 ± 11.2	27.3 ± 14.0	0.129
Wean off	45(93.8%)	22(22.2%)	< 0.001
Peak lactate (mmol/L)	10.9 ± 5.5	16.4 ± 7.7	< 0.001
LVEF+ (%)	35.8 ± 20.6	26.7 ± 21.2	0.029
LDL (mg/dL)	91.9 ± 39.4	80.2 ± 40.0	0.13
#Time interval between witnessed CPR and the establishment of ECMO flow			
*ECMO establish time: interval between the activation of ECMO task force and the establishment of ECMO flow			
+Left ventricular ejection fraction			

Forty-five patients (30.6% of our registry) underwent the procedure of LV decompression (surgical LA drain/surgical apical venting/trans-septal LA drain: 28/4/13 cases), with similar distribution in demographics and ECMO establish time, except that more male patients were in the group of modified LVAD (VA-ECMO vs. Modified LVAD: 82.4% vs 95.6%, p = 0.036). Poorer LVEF rendered more LV decompression (39.4 ± 21.3 vs. 16.2 ± 12.9%, p < 0.001, 95% conf int. 16.0, 30.5). Those patients put on modified LVAD got longer dependence on the mechanical support (3.7 ± 3.7 vs. 20.3 ± 24.1 days, p <

0.001, 95% conf int. -21.4, -11.7) and longer hospital stay (17.8 ± 19.1 vs 31.4 ± 30.7 days, $p = 0.001$, 95% conf int. -21.8, -5.4). Wean-off rate in both modalities of mechanical support was nearly identical (46.1% vs. 44.4%, $p = 1.0$). The mortality rate by interval significantly differed on the 1st day (18.6% vs. 2.2%, $p = 0.008$) and the 3rd day (35.3% vs 17.8%, $p = 0.034$) (Table 3). The Kaplan-Meyer analysis further depicted the survival benefit of modified LVAD (log-rank $p = 0.024$). (Fig. 1)

Table 3
Demographics categorized by VA-ECMO and modified LVAD

	VA-ECMO	Modified LVAD	p value
Case No.	102	45	
Sex			0.036
Male	84(82.4%)	43(95.6%)	
Female	18(17.6%)	2(4.4%)	
Age (yr)	59.8 ± 12.9	57 ± 10.7	0.202
Hypertension	56(54.9%)	24(53.3%)	0.86
DM	39(38.2%)	10(22.2%)	0.061
Smoking	45(44.1%)	22(48.9%)	0.596
Low flow time# (min)	64.5 ± 41.4	50.7 ± 39.3	0.068
ECMO est. time*(min)	26.8 ± 13.0	24.6 ± 13.6	0.355
IHCA	53(52.0%)	24(53.3%)	1.0
OHCA	43(48.0%)	19(46.7%)	1.0
ECMO/VAD days	3.7 ± 3.7	20.3 ± 24.1	< 0.001
Hospital stay(days)	17.8 ± 19.1	31.4 ± 30.7	0.001
Wean off	47(46.1%)	20(44.4%)	1.0
Peak lactate (mmol/L)	14.4 ± 7.4	14.3 ± 7.7	0.944
LVEF+ (%)	39.4 ± 21.3	16.2 ± 12.9	< 0.001
LDL (mg/dL)	84.8 ± 40.8	84.8 ± 39.1	0.997
Mortality			
1 day	19(18.6%)	1(2.2%)	0.008
3 day	36(35.3%)	8(17.8%)	0.034
7 day	45(44.1%)	14(31.1%)	0.149
14 day	54 (52.9%)	17(37.8%)	0.108

#Time interval between witnessed CPR and the establishment of ECMO flow

*ECMO establish time: interval between the activation of ECMO task force and the establishment of ECMO flow

+Left ventricular ejection fraction

	VA-ECMO	Modified LVAD	p value
21 day	56(54.9%)	20(44.4%)	0.284
28 day	60(58.8%)	24(53.3%)	0.589
In-hospital	67(65.7%)	32(71.1%)	0.571
#Time interval between witnessed CPR and the establishment of ECMO flow			
*ECMO establish time: interval between the activation of ECMO task force and the establishment of ECMO flow			
+Left ventricular ejection fraction			

Discussion

Our study has illustrated current practice of ECPR in a referring center in northern Taiwan. The protocol of LV decompression/modified LVAD has been established at the end of 2017, and hence the study began in 2018. First of all, coronary artery disease contributed to 63.3% of our registry of cardiac arrest. Secondly, peak serum lactate and LVEF predicted mortality in our cohort. Most intriguing, modified LVAD, mandated by poorer LVEF, seemed to benefit those who were expected to come with worse outcome.

OHCA vs. IHCA

Our cohort enrolled patients of both OHCA and IHCA of any causes. The composition of diagnosis was compatible with known literature, with the consensus that nearly two-thirds of cardiac arrest events were attributed to coronary artery disease [10–12]. Previously, the survival of OHCA patients was expected to be inferior to IHCA ones, as IHCA patients might merit more efficient CPR efforts. The overall survival to discharge of ECPR-treated IHCA patients was 37.9%, while that of ECPR-treated OHCA patients was heterogeneously between 6.9%and 56.0%, averagely around 20% [13, 14]. OHCA patients were inevitably afflicted with longer low-flow time, which was believed to be detrimental in prognosis. In our series, OHCA patients got longer low-flow time by 35.2 mins, in comparison with their IHCA counterparts. (80.7 ± 44.5 vs 45.6 ± 31.3 min, $p < 0.001$, 95% conf Int. 22.5, 47.8). But this drawback did not necessarily mean poorer systemic perfusion, which could be vividly reflected by peak serum lactate level after resuscitation [15]. The length of low-flow time did not correlate with the peak serum lactate after resuscitation in our study ($R^2 = 0.001$). (Fig. 2a)

Therefore, the peak serum lactate of our OHCA and IHCA patients were not distinct, implying similar sufficiency of resuscitation was achieved. As a result, our OHCA and IHCA patients put on ECPR shared similar rate of weaning-off from mechanical support, and nearly identical rate of survival to discharge. (32.3% vs. 32.9%, p = 1.0). In our opinion, if high quality CPR could be applied consistently and persistently, patients of cardiac arrest could share the same outcome, in spite of the difference of low-flow time.

The prognostic factors: peak serum lactate and LVEF

The peak serum lactate and LVEF cast significant predictability. Those with higher lactate level or poorer LV function suffered higher mortality rate in our cohort. These two factors have been well reported to tell the prognosis in the literature [16]. In our study, the low-flow time did not differ between those who survived and those who succumbed to (60.0 ± 44.1 vs. 60.4 ± 39.8 mins, $p = 0.948$). Neither were the peak serum lactate ($R^2 = 0.001$) (Fig. 2) nor the LVEF ($R^2 = 0.002$) correlated with the low-flow time. (Fig. 2b). Furthermore, the peak serum lactate and LVEF were not interactive and no correlation existed ($p = 0.956$). In addition, the duration of dependence on mechanical support did not influence the outcome (survival vs. mortality 12.2 ± 20.9 vs. 7.1 ± 11.9 days, $p = 0.065$), but it was the wean-off rate that mattered (93.8 vs. 22.2%, $p < 0.001$). In other words, as long as the patient could get rid of the indwelled machinery, he or she may be able to survive to discharge, regardless of how long the patient was put on the machine.

The LV decompression/modified LVAD

So far, our study demonstrated comparable and compatible characters with currently available literature, such as diagnosis composition, mortality of ECPR-treated IHCA, prognostic predictability of peak serum lactate and LVEF. This legitimized further extrapolation of our cohort, to explore the efficacy of LV decompression in the care of cardiac arrest patients. In addition to equal distribution of demographics in the two groups of VA-ECMO and modified LVAD, the highly predictive parameter, peak serum lactate, was not distinct among them. Even the low-flow time was similar. LVEF was the only different parameter. But in this category, it should be regarded as the driving factor that rendered urgent indication for LV decompression, rather than the contributor to the outcome. The ration could be, the lower the LVEF, the more the need for LV decompression, and resultantly, the better the survival. Based on the cross-sectional mortality, the modified LVAD offered survival benefit over VA-ECMO by 3 days in our ECPR patients, which was further illustrated by Kaplan-Meyer analysis.

In the study conducted by Chen YS et al., the authors found that ECPR did benefit IHCA patients, but OHCA patients with longer low-flow-time were not enrolled [17]. There was no further delineation of the role of LV decompression then. To our knowledge, there were only 3 individual series that comprised more than 20 cases of LV decompression: Centofanti P et al. 24 cases, Eastaugh LJ et al. 44 cases, Hacking DF et al. 49 cases [18–20]. The latter two were studying pediatric patients, and only Centofanti P et al. addressed the survival benefit of trans-apical LV venting in adults with cardiogenic shock put on VA-ECMO. Moreover, none of the above mentioned cardiac arrest. Our cohort enrolled 45 cases of LV decompression, by direct surgical LV venting, upstream LA drainage either by sternotomy, or peripheral trans-septal approach. In addition, these 45 patients were even more complicated, as they suffered from cardiac arrests and ensuing resuscitation. Our patients of both OHCA and IHCA could have more survival probability, if modified LVAD were appropriately indicated.

Study limitations

This is a prospective cohort study, and inheriting the drawback of selection bias was not inevitable. However, nearly all items of demographic were evenly distributed, which should offset the influences derived from shortcomings of a non-randomized design.

Conclusions

Our prospective cohort, enrolling both OHCA and IHCA patients put on ECPR, implied that fair outcomes could be achieved, as long as high quality CPR could be persistently applied, regardless of how long the low-flow time was. Peak serum lactate and LVEF were proved again to be closely correlated to outcomes. Moreover, the procedure of LV decompression could render further survival benefit to those with poorer LV function.

List Of Abbreviations

ECPR
extra-corporeal cardiopulmonary resuscitation
OHCA
out-of-hospital cardiac arrest
IHCA
in-hospital cardiac arrest
ECMO
extra-corporeal membranous oxygenation
LVAD
left ventricular assist device
LVEF
left ventricular ejection fraction

Declarations

Ethics approval and consent to participate: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This prospective cohort was approved and scrutinized by the Institutional Review Board of Far-Eastern Memorial Hospital, New Taipei City, Taiwan.

The concept of patient involvement was incorporated in the study design, especially in the process of enrollment. Informed consent was the basic requirement. The pros and cons of the intended treatment were well discussed with the patient or the patient's legitimate delegates, using laypersons' language to avoid the gap of information. We then revisited our aims and revised the research plans to align them better with things that patients cared about the most. The patient or his/her legitimate delegates were all well informed and allowed to express their thoughts during the treatment and study process.

Consent for publication: All authors have provided consent for publication of the manuscript.

Availability of data and materials: all information as available by contacting the correspondent author Dr. Hsin HT. by email

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Authors' contributions: H-TH, conducted the study, analysis and finished the manuscript drafting. K-MC organized the team and designed the study protocol, Y-CW finished the data collection, others performed the procedures of ECMO/modified LVAD, dedicated care and offered draft suggestions.

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Figures

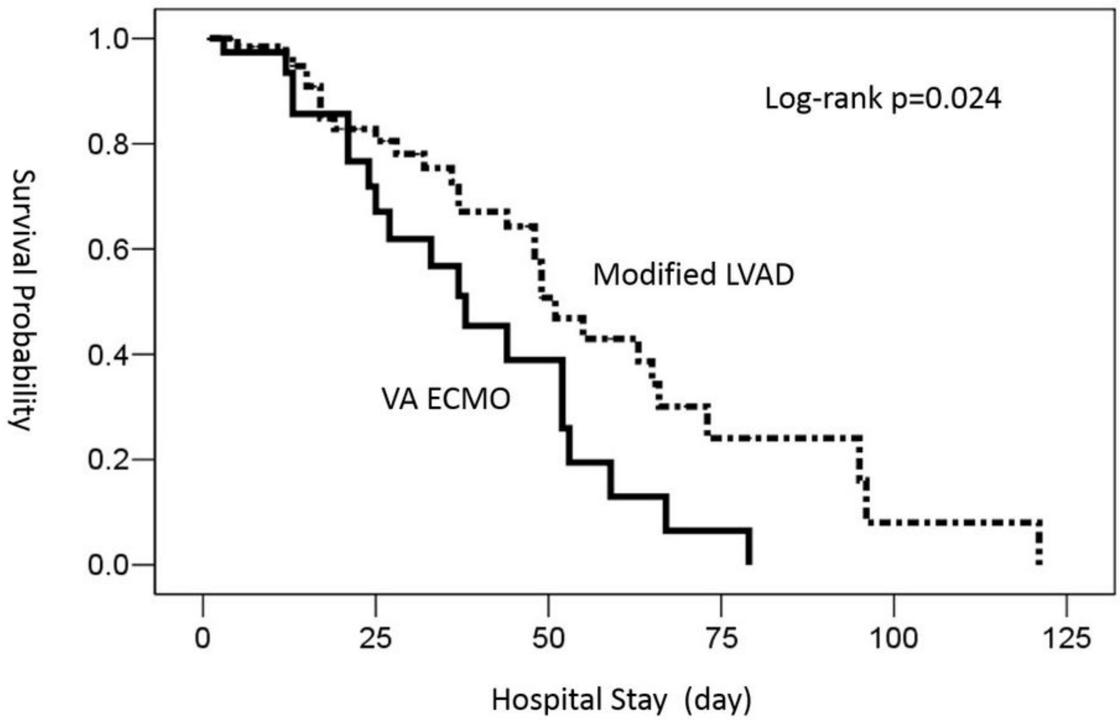

Figure 1

The Kaplan-Meyer survival curve of VA-ECMO vs. modified LVAD showed significant survival benefit of modified LVAD.

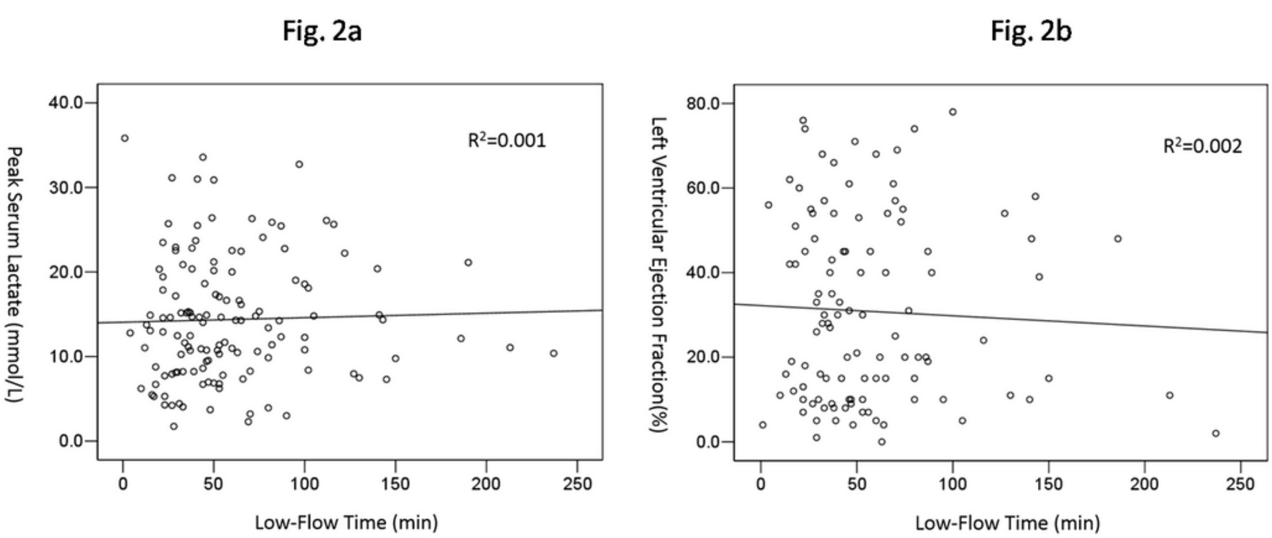

Figure 2

2a The low-flow time was not correlated with peak serum lactate 2b The low-flow time was not correlated with left ventricular ejection fraction during mechanical support